

Estimating protozoal fate and transport in a wetland system using a model-based approach

Miles E. Daniels^(a), Fred G.R. Watson ^(a), Woutrina A. Miller ^(b), Jennifer Hogan ^(b)

^a California State University, Monterey Bay

^b University California, Davis
mdaniels@csumb.edu

Introduction

The protozoal pathogens *Cryptosporidium* ssp., *Giardia* ssp., and *Toxoplasmosis* ssp. exist in California waterways. These pathogens pose a health risk as they can survive in aquatic systems for long durations, have a low infectious dose, and show resistance to most conventional methods of water treatment (Fayer et al. 2004). Protozoal pathogens also negatively impact California’s coastal wildlife, causing mortality and disease in some species (Miller et al. 2002; Conrad et al 2005).

Using wetlands as a water quality improvement practice has been shown to reduce the concentrations of protozoal oocysts in certain settings (Gerba et al. 1999). The mechanisms responsible for removal, however, are not completely understood. Knowledge of removal mechanisms, however, is beneficial when evaluating the effectiveness of using such systems to treat this form of water pollution.

Modeling oocyst fate and transport represents one method of studying mechanisms thought to influence these pathogens in wetland systems.

Objectives

1. Develop a simulation model to predict the fate and transport of protozoal oocyst in wetland settings.
2. Calibrate the simulation model to the hydraulic conditions of a wetland research site.
3. Estimate protozoal settling and its impact on protozoal removal expected at the wetland research site using data from laboratory scale experiments.

Methods

1. Model Development

- I used a partial differential equation to represent a one-dimensional advection-dispersion model:

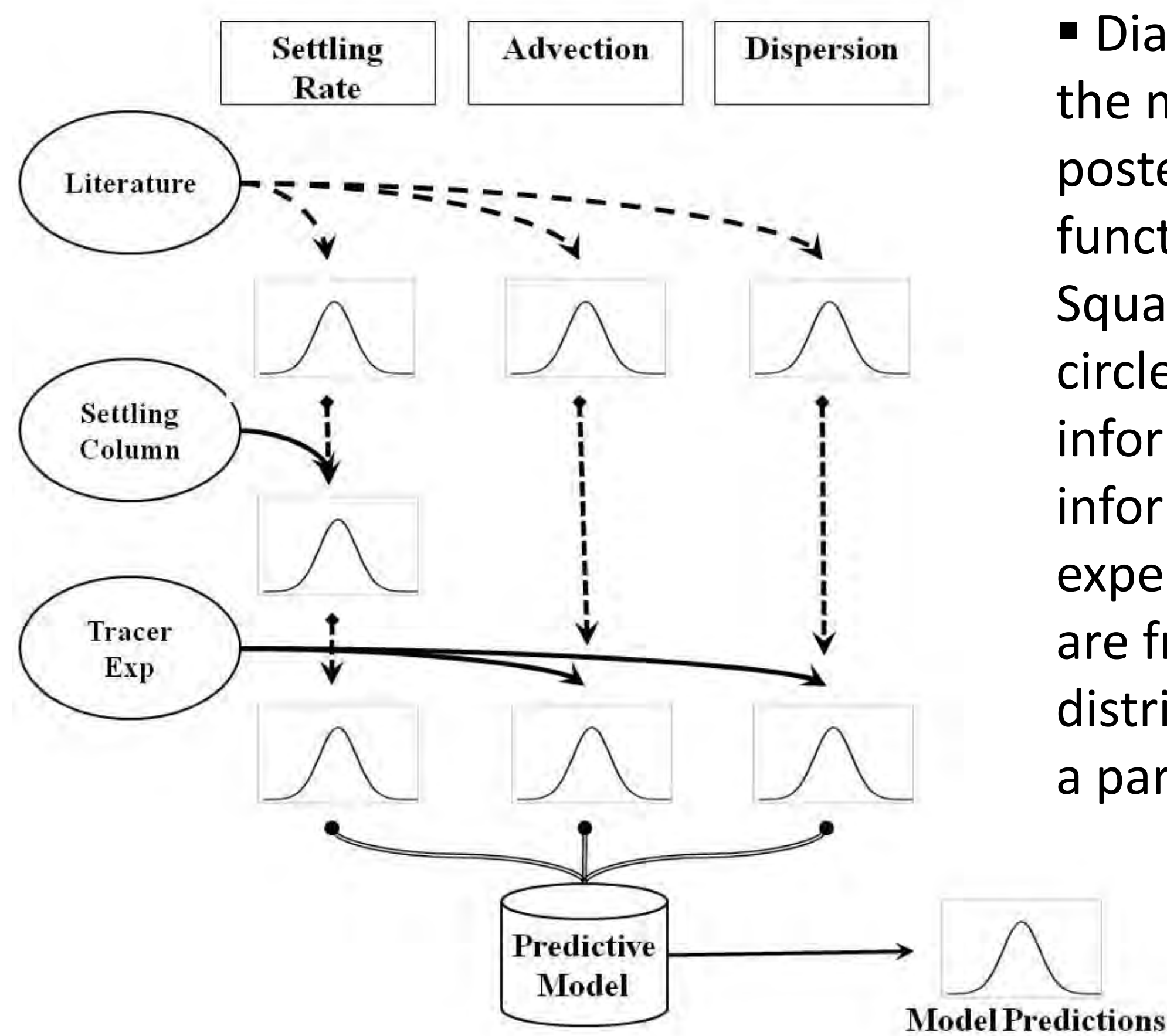
$$\frac{\partial c}{\partial t} = -U \frac{\partial c}{\partial x} + E \frac{\partial^2 c}{\partial x^2} - \left(\frac{V_s}{d} \right) c$$

where for each n reaches linked along the length, x , of a channel, c (# L⁻³) is the concentration of the constituent in question, U (L T⁻¹) is the channel advection rate, E (L² T⁻¹) is the turbulent diffusion coefficient, V_s (L T⁻¹) is the settling velocity of particles, and d (L) is the depth of the water.

- I employed Bayesian inference to parameterize the simulation model, where given a set of feasible parameters for a given model (M) and evidence (E), Bayes theorem is defined as:

$$P(M|E) = \frac{P(M) L(E|M)}{C}$$

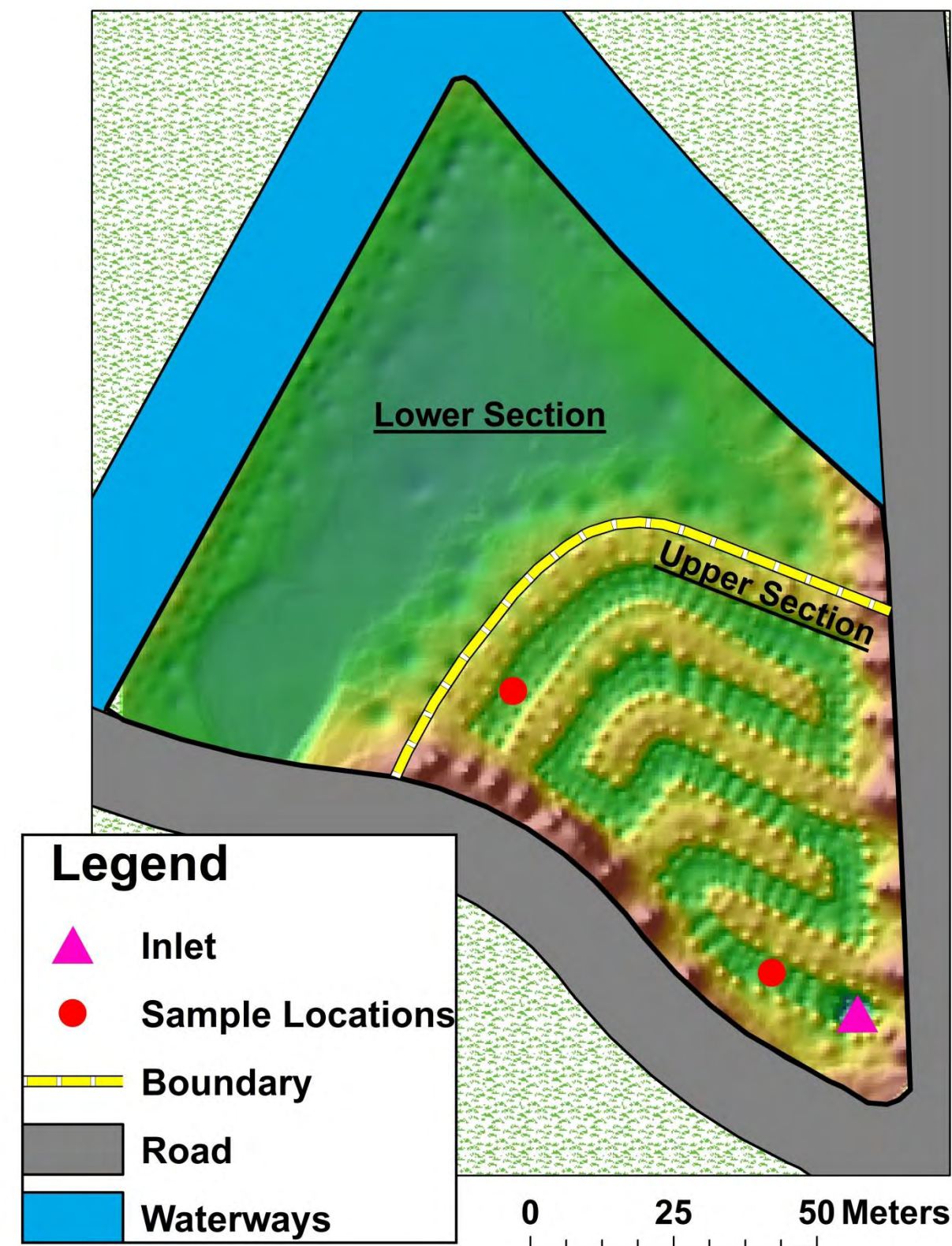
where $P(M|E)$ is a posterior probability density function for the model parameters, $P(M)$ is a prior probability defined for all feasible parameters in a model, $L(E|M)$ is the likelihood of simulating the evidence given a parameter set of a model, and C is a scaling constant to ensure the posterior probability density function sums to one.



- Diagram to the left summarizes the methodology to produce posterior probability density functions (PDF) for parameters. Squares represent parameters, circles represent sources of information, solid arrows are information added to PDFs from experiments and dashed arrows are from literature sources, and distributions represent the PDF of a parameter.

2. Wetland Hydraulics

- To examine the hydraulic conditions of the wetland research site, a conservative water tracer (sodium bromide) was used.
- Sodium bromide was injected at the inlet of the wetland and water samples were collected at two locations downstream.
- Samples were analyzed for sodium bromide concentration using Ion Chromatography methods.

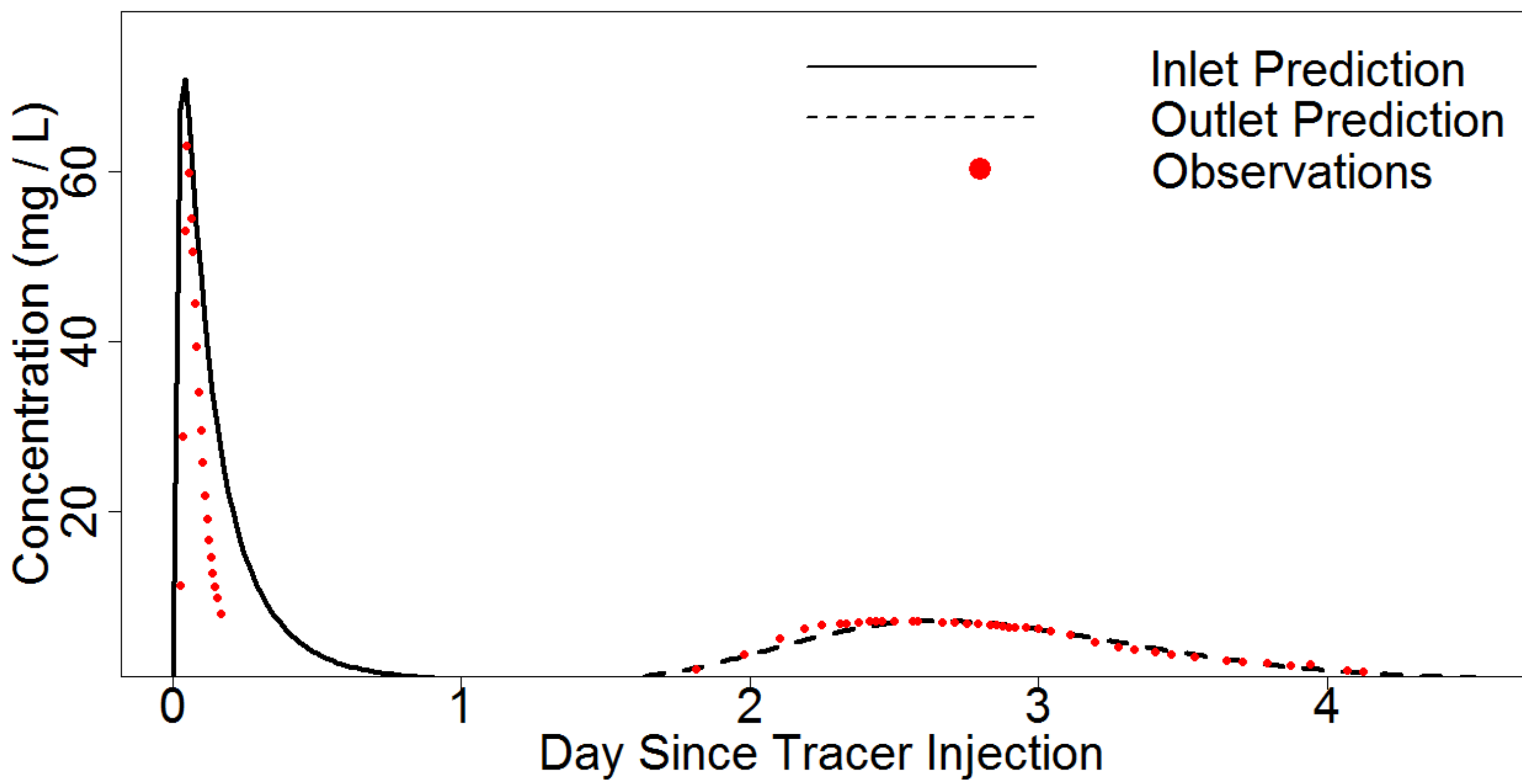


- The topography of the wetland research site is shown to the left. The wetland is an offline system that has two delineated sections. The upper portion is a sinuous engineered channel with a length and width of 280 and 6 m respectively, has a maximum depth of 0.40 m, and volume of 800 m³ depending on water level. The lower section is an intermittent pond feature with an average depth of 0.15 m. and volume of approximately 400 m³. Water inflow is supplied to the system and controlled using a mechanical pump. The water tracer experiment occurred in the upper section of the wetland, with the tracer injected at the inlet.

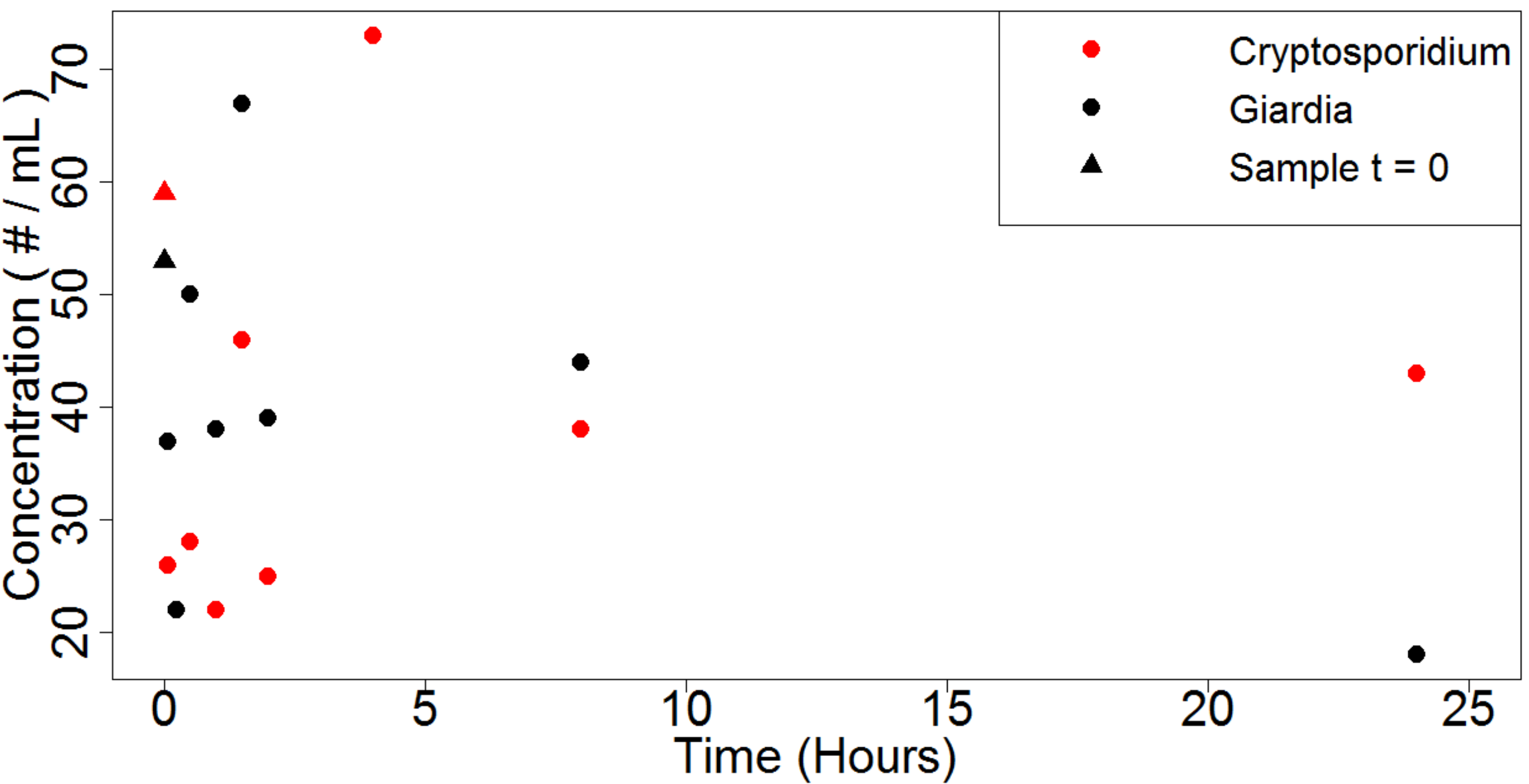
3. Protozoal Settling

- Settling columns were used to examine the rate protozoal oocysts settled out of water.
- Columns were filled with a known number of protozoal oocysts and homogenized.
- Samples were collected with syringes from side ports at pre-determined times and processed for oocyst concentration by enumeration via microscopy.

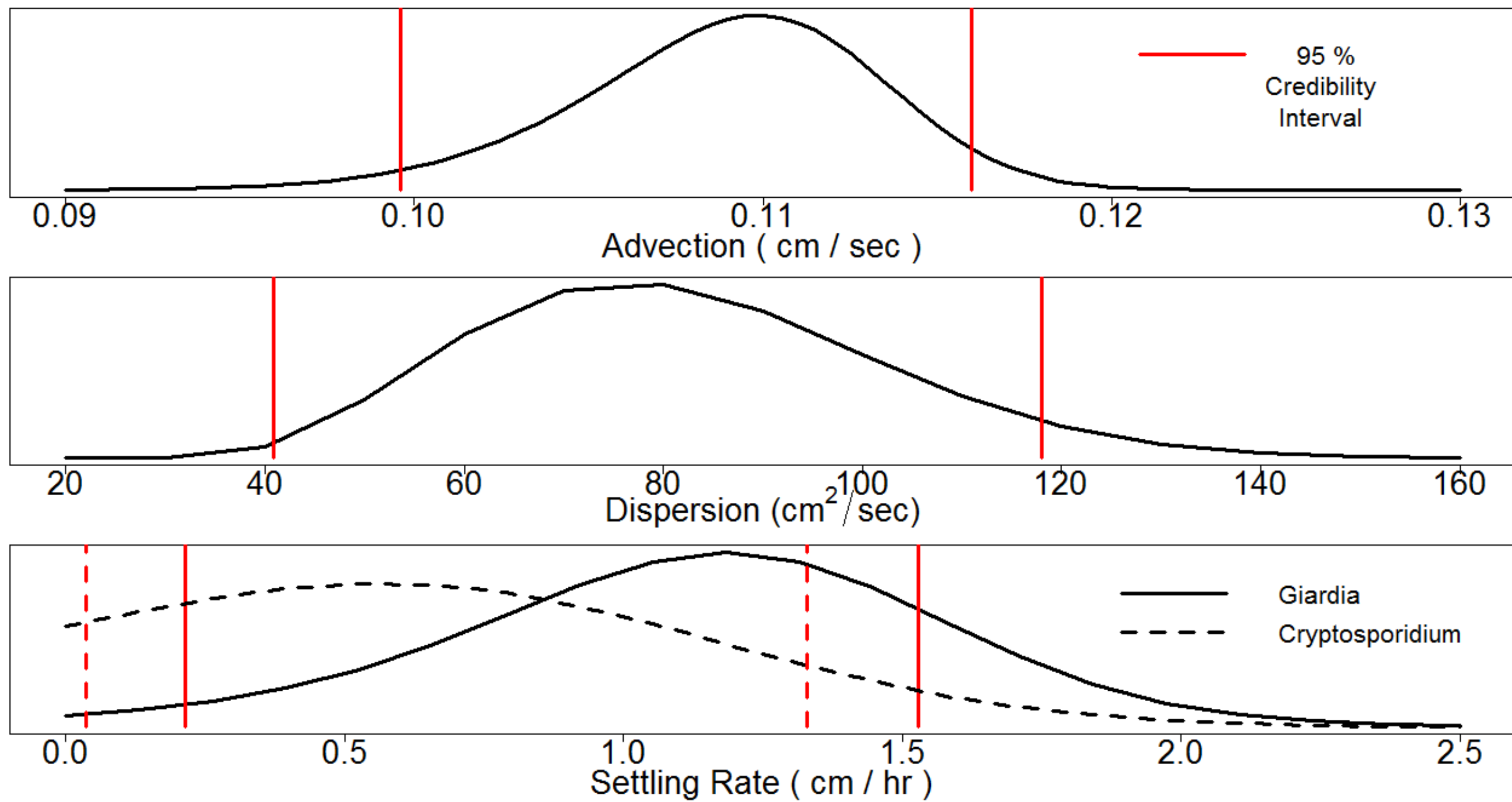
Results



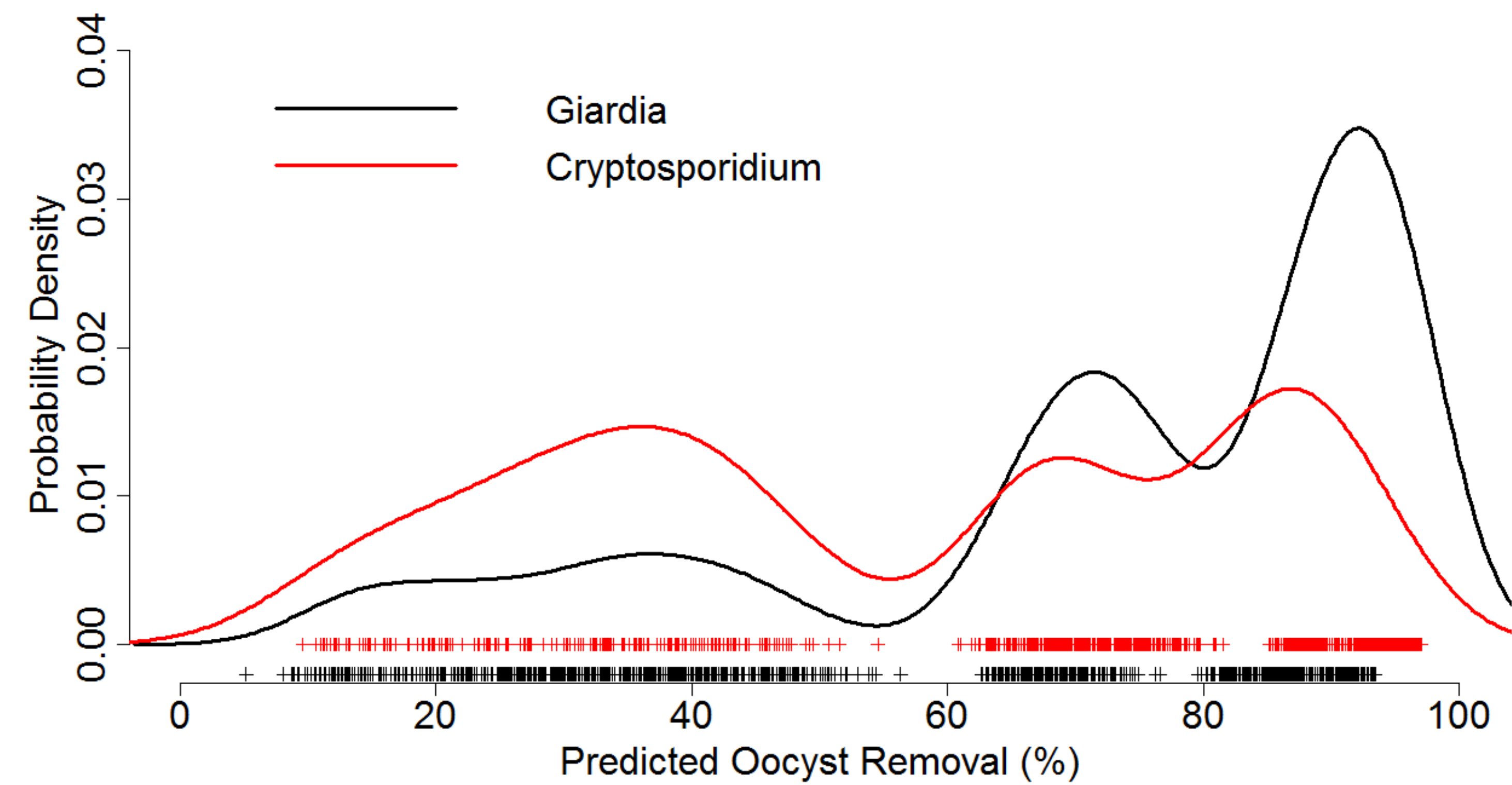
- Data from the tracer experiment conducted at the wetland research site and the simulation model fit.



- Plot of observed oocyst concentrations from the settling column experiments.



- Posterior probability density functions with 95% credibility intervals for advection, dispersion, and settling rate parameters that were produced using data from the wetland tracer and settling column experiments.



- Model predictions of the removal efficiency for the upper section of the wetland research site. Predictions were obtained by taking 1000 random samples (+) from the posterior probability density functions of the model parameters.

Conclusions

- The simulation model is able to represent accurately the hydraulics of the research wetland.
- Settling column experiments demonstrate that *Giardia* and *Cryptosporidium* settle out of water in a system assumed to have no advection or dispersion.
- *Giardia* is estimated to have a higher settling rate compared to *Cryptosporidium*.
- Mean removal efficiency of the upper section of the wetland research site is predicted to be 73% (+/- 23 %) for *Giardia* and 55% (+/- 26 %) for *Cryptosporidium*.

Future Work

- Confirm settling characteristics of protozoal oocysts at the wetland research site using release studies of surrogate oocysts.
- Incorporate additional parameters into the simulation model and their effects on oocyst fate and transport :
 - Water Temperature
 - Salinity
 - Suspended Solids Concentration

References

▪ Conrad, P.A., M.A. Miller, C. Kreuder, E. James, J. Mazet, H. Dabritz, D. Jessup, F. Gulland, and M. Grigg. 2005. Transmission of *Toxoplasma*: clues from the study of sea otters as sentinels of *Toxoplasma gondii* flow into the marine environment. *International Journal Parasitology* 35: 1125-1168.

▪ Fayer R, Dubey JP, Lindsay DS. 2004. Review: Zoonotic protozoal: from land to sea. *Trends in Parasitology* 20: 531-536.

▪ Gerba CP, Thurston JA, Falabi JA, Watt PM, Karpiscak MM. 1999. Optimization of Artificial Wetland Design for Removal of Indicator Microorganisms and Pathogenic Protozoal. *Water Science and Technology* 40: 363-368.

▪ Miller MA, Gardner IA, Kreuder C, Paradies DM, Worcester KR, Jessup DA, Dodd E, Harris MD, Ames JA, Packham AE, Conrad PA. 2002. Coastal freshwater runoff is a risk factor for *Toxoplasma gondii* infection of southern sea otters (*Enhydra lutris nereis*). *International Journal of Parasitology* 32: 997-1006.